Predicting Trophic Interactions and Habitat Utilization in the California Current Ecosystem

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LONG-TERM GOALS

While specifically focusing on trophic interactions affecting habitat utilization and foraging patterns of California sea lions (CSL) in the California Current Large Marine Ecosystem (CCLME), the long-term goal of our modeling approach is to better understand and characterize biological "hotspots" (i.e., the aggregation of multiple marine organisms over multiple trophic levels) off the U.S. west coast and in other regions where similar fully-coupled ecosystem models may be implemented. As such, our research represents a major step towards a predictive model that can provide fundamental knowledge about: (1) the spatial and temporal distribution of key marine organisms over multiple trophic levels, and (2) natural and anthropogenic variability in ecosystem structure and trophic interactions

OBJECTIVES

The main research objective is to quantify habitat utilization and trophic interactions in the CCLME by considering patterns of covariability between environmental variables (e.g., temperature, primary production) and foraging patterns and success of middle (sardine and anchovy) and higher (sea lions) trophic level species. To this end, our numerical experiments are designed to isolate patterns of variability on seasonal to interannual timescales by identifying shifts in habitat utilization (e.g., shelf vs. offshore foraging) in the CCLME during "normal" and "extreme" years.

APPROACH

Our fully-coupled ecosystem modeling framework consists of a lower trophic level ecosystem model (NEMURO) embedded in a regional ocean circulation model (ROMS), and both coupled with a multi-species individual-based model (IBM) for forage fish (sardine and anchovy) and California sea lion. The IBM for sea lion includes bioenergetics and movement components based on available data on their foraging patterns and diet in the CCLME. The numerical experiments with the ecosystem model are designed to identify trophic interactions and habitat utilization on various timescales, including periods of extreme variability (e.g., El Niño, La Niña, delayed upwelling). Our team includes expertise in areas of climate modeling in upwelling regions (E. Curchitser), physical-biological modeling in the CCLME (J. Fiechter and C. Edwards), data assimilation (A. Moore), forage fish ecology (K. Rose) and pinniped ecology (D. Costa). The team also includes a postdoctoral research associate (L. Huckstadt)

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working on the bioenergetics and behavior components for the sea lions under the supervision of D. Costa.

WORK COMPLETED

We completed the second year of the project, and our progress to date is on track with respect to the proposed milestones for Year 2. As of 1 September 2014, we have achieved the following main tasks:

(1) Evaluation of a 50-year simulation of the fully coupled ecosystem model (with sardine and anchovy only) to determine which environmental factors controlled forage fish population dynamics in the CCLME during 1959-2008.

(2) Implementation of the CSL IBM component in the ecosystem model with full bioenergetics and various movement algorithms, such as kinesis and restricted-neighborhood search.

(3) Preliminary simulations of the fully coupled ecosystem model (with sardine, anchovy and CSL) for climatological conditions, El Niño (1998) and La Niña (1999) conditions, and delayed upwelling conditions (2005).

The completion of task (1) led to the submission of two manuscripts to Progress in Oceanography describing the fully coupled ecosystem model framework (Rose et al.) and the environmental factors controlling sardine and anchovy population abundance in the simulation (Fiechter et al.). The completion of tasks (2) and (3) led to a presentation (Fiechter et al.) at the IMBER 2014 Open Science Conference in the session “End-to-end modelling for research and management”.

RESULTS

A. Baseline simulation (1959-2008)

We used the 50-year simulation of the ecosystem model to investigate how environmental processes control sardine and anchovy population dynamics in the CCLME. Simulated abundances indicate that anchovy peaked during the early 1970’s and the 1980’s, while sardine remained relatively low until steadily increasing from the mid 1990’s on. The low frequency variability in simulated adult biomass for each species compares favorably with historical observations, especially in reproducing the overall increase (decrease) of sardine (anchovy) population abundance starting in the early 1990’s (Fig. 1).

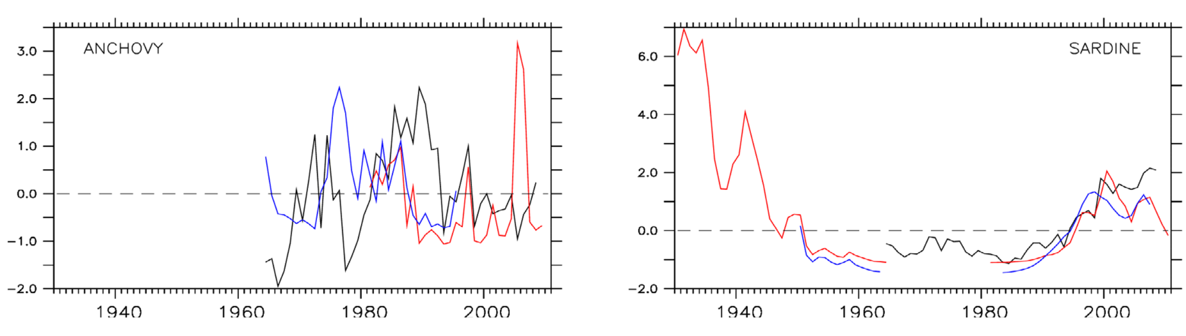

Figure 1. Standardized anomalies for anchovy (left) and sardine (right) biomass. Black lines: 50-year simulation. Red lines: observed data from Hill et al. (2009) for sardine and Fissel et al. (2011) for anchovy. Blue lines: observed data from Barange et al. (2009) for both species.

Simulated adult population fluctuations are associated with adult growth (via egg production) and prey availability for anchovy (Fig. 2), while they depend on egg survival and temperature for sardine (Fig. 3). The analysis also hints at potential linkages to known modes of climate variability, whereby changes in adult abundance are related to ENSO for anchovy and to the PDO for sardine. This finding is consistent with modes of interannual and decadal variability that would alternatively favor anchovy during years of cooler temperatures and higher prey availability, and sardine during years of warmer temperatures and lower prey availability.

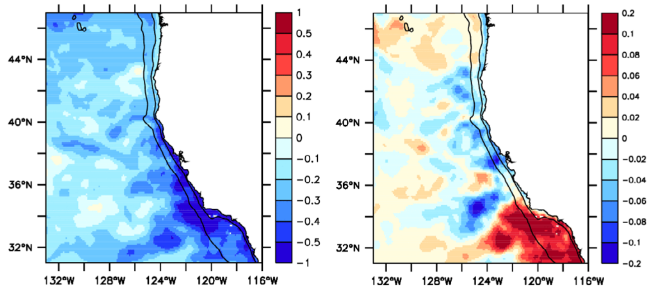

Figure 2. Environmental conditions from the 50-year simulation favoring anchovy abundance via increased adult growth and egg production. Left: temperature anomalies (°C). Right: predatory zooplankton (krill) anomalies (mmolN m^{-3}).

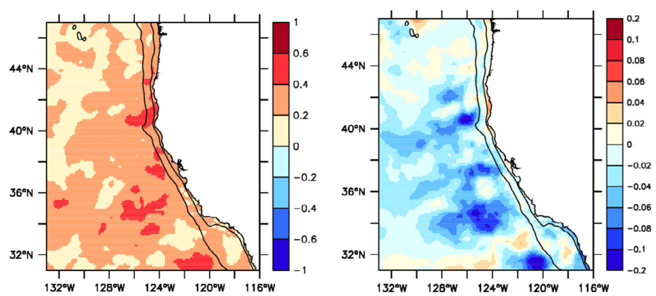

Figure 3. Environmental conditions from the 50-year simulation favoring sardine abundance via increased egg survival. Left: temperature anomalies (°C). Right: predatory zooplankton (krill) anomalies (mmolN m^{-3}).

B. Simulations for normal vs. extreme years

Since sea lions respond to changes in sardine and anchovy abundance via consumption to meet their bioenergetics requirements, we expect that the model will show different foraging patterns and/or growth conditions during anomalous years (e.g., ENSO events). During the second year of the project, we implemented the CSL bioenergetics and movement into the ecosystem model and ran a series of simulations for normal condition (i.e., climatological forcing) and extreme years (i.e., 1998 El Niño, 1999 La Niña and 2005 delayed upwelling). To look at spatial variability, we considered two CSL "populations", one foraging along the Big Sur coast and the other in the Gulf of the Farallones. A restricted-neighborhood search algorithm was used to represent foraging behavior, and the duration of foraging trips and haul out periods were dynamically adjusted based on feeding success (i.e., sea lions seeking to maintain a constant weight). Preliminary results indicate that ROMS and NEMURO reproduce expected variability during extreme years, with a warmer (cooler) and less (more) productive coastal upwelling system during 1998 and 2005 (1999) compared to "normal" conditions (Fig. 4). The results also show that these anomalies lead to changes in sardine and anchovy abundance off the central California coast, which ultimately impacts CSL foraging success (Fig. 5). Because the search algorithm use for behavior makes the sea lions particularly efficient at finding food, spatial and temporal differences between normal and extreme conditions are generally small. During the third year of the project, we plan to refine the movement algorithm by using tracking data for CSL off central California from the TOPP Program. For example, we will determine from the observations if there are environmental cues (e.g., temperature) that sea lions are following while searching for prey. We will then incorporate this information into a kinesis-type movement algorithm to investigate whether the model can reproduce expected changes in foraging patterns and feeding success.

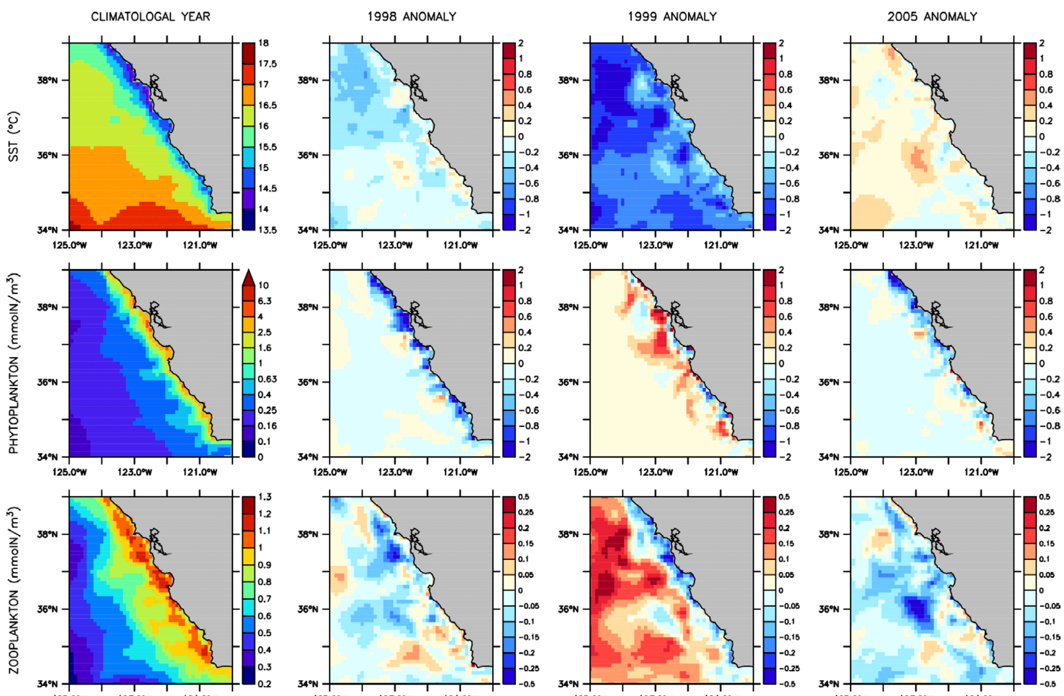

Figure 4. Sea surface temperature (°C; top), phytoplankton concentration (mmolN m^{-3}; middle) and zooplankton concentration (mmolN m^{-3}; bottom) during normal and extreme years off central California. Far left: annual mean climatology. From center left to far right: annual mean anomalies with respect to climatology for 1998 (El Niño), 1999 (La Niña) and 2005 (delayed upwelling).

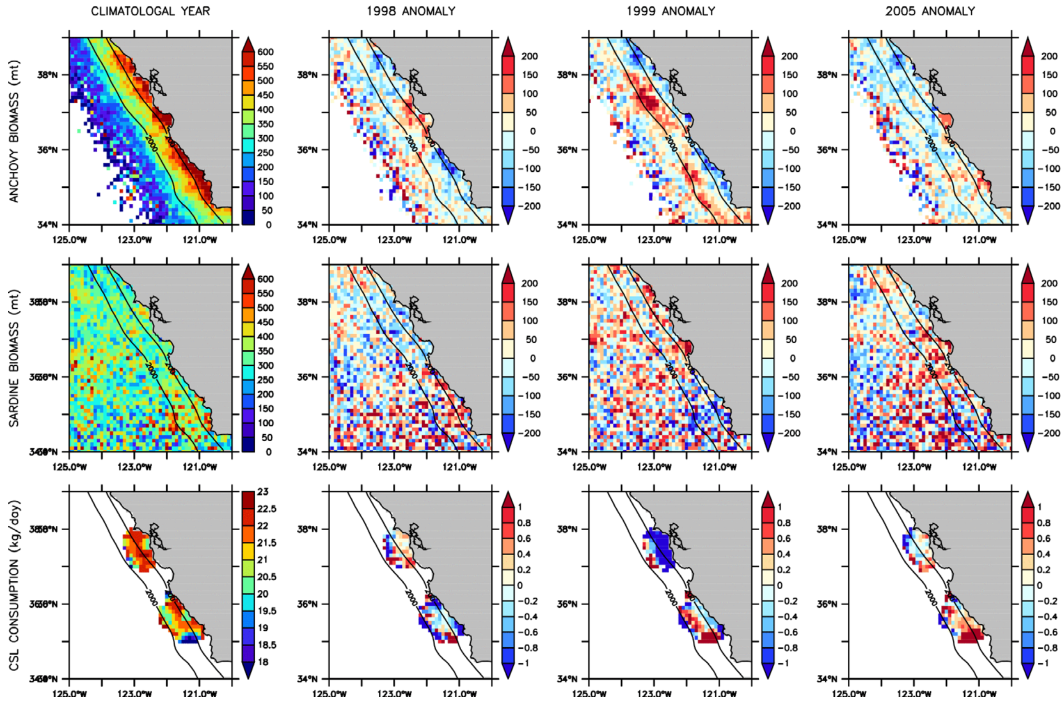

Figure 5. Anchovy biomass (mt; top), sardine biomass (mt; middle) and CSL daily consumption (kg prey; bottom) during normal and extreme years off central California. Far left: annual mean climatology. From center left to far right: annual mean anomalies with respect to climatology for 1998 (El Niño), 1999 (La Niña) and 2005 (delayed upwelling).

IMPACT/APPLICATIONS

While focusing on the development of an individual-based model for California sea lions and its incorporation into a fully-coupled ecosystem model, the proposed research will pave the way for building a more comprehensive end-to-end modelling framework that can account for multiple species across several trophic levels. This information will eventually lead to characterizing biological "hotspots" (i.e., the aggregation of multiple marine organisms over multiple trophic levels) in the CCLME, or other regions where similar fully-coupled ecosystem models may be implemented (e.g., Southern Ocean). A main advantage in using model output to diagnose the occurrence and persistence of biological hotspots is the access to all physical and biological variables (e.g., water column temperature, primary production, growth rates, behavioral cues) over the range of spatial and temporal scales needed to determine which particular environmental conditions and which particular foraging strategies were conducive to aggregation over multiple trophic levels. In the future, our ecosystem model could be used to predict how climate variability may impact suitable habitat distributions in the CCLME or other regions of the world oceans.

RELATED PROJECTS

PI Fiechter and co-PIs Edwards and Moore are collaborating on an NSF-funded project (PI Moore; award dates: 04/01/2011-03/31/2015) entitled: "Variability of the California Current System Derived from 4D-Var Circulation Estimates". Our current ONR project will benefit from the 4D-Var circulation estimates to improve the accuracy with which the integrated ecosystem model reproduces environmental variability in the California Current (e.g., temperature, phytoplankton). The 4D-Var work will also inform our proposed research on which aspects of seasonal and interannual variability may not be adequately reproduced by ROMS without use of data assimilation.

PUBLICATIONS

Fiechter, J., K.A. Rose, E.N. Curchitser, K. Hedstrom (2014). The role of environmental controls in determining sardine and anchovy population cycles in the California Current: Analysis of an end-to-end model, Progress in Oceanography.

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